Constraints on the provenance of the uppermost allochthonous terrane of the NW Iberian Massif: inferences from detrital zircon U–Pb ages

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ABSTRACT

Insight into the origin and pre-orogenic palaeogeographical links of terranes involved in the assembly of collisional mountain belts is fundamental to the understanding of orogenic processes. Here we address the provenance and possible tectonic settings of the uppermost allochthonous terrane of the NW Iberian Variscan Belt through a 213-nm Laser Ablation ICP-MS study of U–Pb ages of detrital zircons. The age groups of zircons from greywackes in this terrane (c. 480–610, 1900–2100, 2400–2500 Ma) and the lack of Mesoproterozoic zircons suggest an origin in a Neoproterozoic – Early Palaeozoic peri-Gondwanan realm along the periphery of the west African craton. It is further inferred that the greywackes were deposited in the periphery of a crustal unit that had been detached from the Gondwanan margin in relation to the opening of the Rheic ocean in Cambro-Ordovician times. This terrane was thrusted back upon the Gondwanan margin during the course of the Variscan collision and closure of the intervening ocean.

Introduction

Present-day understanding of the Variscan Laurentia–Gondwana collision in Europe owes much to structural, metamorphic and geochronological studies carried out on the Allochthonous Complexes (AC) of NW Iberia (e.g. Martínez Catalán *et al.*, 1997, 1999, and references therein). These studies have provided first-order constraints on the tectonothermal events involved in the Laurentia–Gondwana collision within the western European realm of the Variscan belt.

A major issue that has not been fully addressed in previous studies is the provenance of the allochthonous terranes thrusted upon the Gondwanan margin (relative autochthon) during the course of the Variscan collision (e.g. Martínez Catalán *et al.*, 1996, 1997, 1999; Matte, 2001). It is generally agreed that the autochthonous terranes of NW Iberia (Fig. 1) were part of the Gondwanan continental margin, but there is little evidence as regards the parentage of the allochthonous terranes. This issue is directly connected to the controversy regarding the pre-Variscan evolution of these geological units (Martínez Catalán *et al.*, 1997; Abati *et al.*, 1999; Matte, 2001).

In this work we investigate the provenance and pre-Variscan tectonic settings of the uppermost terrane of the AC of NW Iberia through a study of detrital zircon U–Pb ages in low-grade greywackes located in the uppermost structural unit of the nappe pile (Fig. 1). This study is the first of its kind carried out on the Variscan AC of Iberia and is aimed at providing new constrains on their tectonic and palaeogeographical evolution.

Geological setting

The Allochthonous Complexes of NW Iberia (Fig. 1), whose main geological features have been described in detail elsewhere (Martínez Catalán *et al.*, 1999, and references therein), consist of units stacked upon a relative autochthon considered to be the continental margin of Gondwana. These complexes, exposed as structural synforms, are formed by units with different tectonothermal histories and are interpreted to be dismembered fragments of a Variscan accretionary complex (Martínez Catalán *et al.*, 1997, 1999). Three tectonometamorphic units have been distinguished in the AC (Arenas *et al.*, 1995) based on their structural position and tectonometamorphic evolution: basal, intermediate (ophiolitic) and upper units.

The basal units consist of schists, paragneisses, and Early Ordovician felsic and mafic igneous rocks that underwent subduction and high-pressure metamorphism at 380–365 Ma during the closure of an oceanic realm (Arenas *et al.*, 1995; Martínez Catalán *et al.*, 1996). They are considered to represent the external edge of the Gondwanan margin involved in the collision. The ophiolitic unit (Díaz García *et al.*, 1999) structurally overlies the basal units and represents an Early Devonian oceanic crust. The upper units comprise an outboard terrane tectonically emplaced upon the ophiolitic unit. These upper units can be subdivided into two subunits: high-pressure/high-temperature (HP-HT) and intermediate-pressure (IP) units. The HP-HT subunit contains eclogite- to granulite-facies paragneisses, ultramafic rocks, metagabbros and orthogneisses of continental and arc affinities. The age of the HP-HT metamorphism is a matter of debate, some authors favouring an Early Devonian age for this event (Ordoñez Casado *et al.*, 2001) and others an Early Ordovician age (Kuijper, 1979; Fernández-Suárez *et al.*, 2002b). The intermediate pressure unit (IP) is placed structurally on top of the HP-HT unit through a wide shear zone and consists of a sequence of low- to high-grade metasediments intruded by tholeiitic metagabbros

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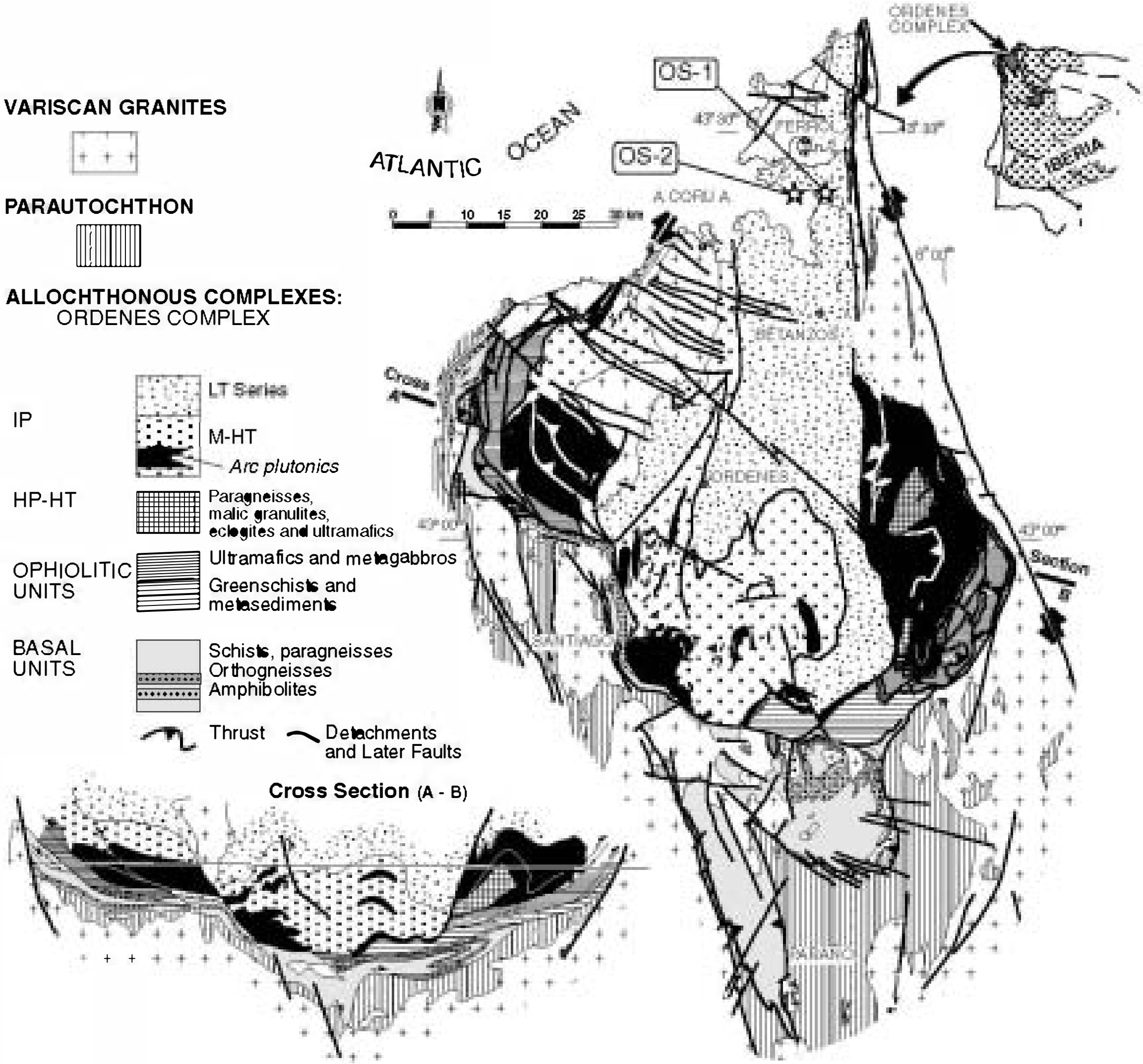

Fig. 1 Geological map and cross-section of the Ordenes Complex showing the main units and the location of greywacke samples. Illustration in the top right-hand corner shows autochthonous NW Iberia (Gondwanan margin) in a dotted pattern and the allochthonous complexes in grey.

and granodioritic to tonalitic orthogneisses at *c*. 500 Ma (Abati *et al*., 1999). These intrusions have been interpreted as arc-related rocks (Abati, 2000).

The uppermost part of the IP unit of the outboard terrane (the Betanzos Unit) is made up of siliciclastic greenschist-facies rocks and is in tectonic contact with the underlying higher-temperature metamorphic rocks. The lower part of the Betanzos Unit (Fig. 1) is a *c*. 1000-m-thick metasedimentary succesion consisting of black metapelites with alternations of quartzites. The upper part of the Betanzos unit consists of *c*. 1500 m of alternations of metagreywackes and slates with minor conglomerate levels. The whole unit is interpreted to represent a flyschoid succession deposited by a turbiditic system (Matte and Capdevilla, 1978; Gutiérrez Alonso *et al*., 2000) and has several characteristics of sediments deposited in amagmatic peri-arc basins. The abundance of plagioclase, volcanic quartz and fragments of igneous rocks, combined with the apparent lack of volcanic levels, suggest that this unit may represent a fore-arc basin fill (Diaz Garcia, 2000).

Two samples of coarse greywackes were collected in the upper part of the Betanzos Unit (OS-1 and OS-2, Fig. 1).

Analytical techniques

U–Pb dating of individual zircon grains was performed using 213-nm laser ablation quadrupole ICP-MS at The Natural History Museum (London). The 213-nm laser system is a novel development for LA-ICP-MS U–Th–Pb isotope ratio determinations in zircons (Jeffries and Fernández-Suárez, 2001; Jeffries, 2001). Further details on the technique and analytical procedures are given elsewhere (Fernández-Suárez *et al*., 2000). Zircons separated by conventional techniques were set in synthetic resin mounts, polished and cleaned in a warm HNO_3 ultrasonic bath. Cathodoluminiscence (CL) and back-scattered electron (BSE) imaging was performed and only zircons considered to be homogeneous on the basis of their CL/BSE images, or large homogeneous cores, were analysed. Analyses were performed using a 213-nm Nd:YAG laser ablation system (New Wave Research, USA) coupled to a quadrupole-based ICP-MS (PlasmaQuad 3, Thermo Elemental, UK) with an enhanced sensitivity (S-option) interface. To reduce the effects of interelement laser-induced fractionation, the zircons were ablated at the lowest power density required to couple to the sample (pulse energy = 0.15 mJ per pulse). During ablation, the sample was moved relative to the beam along raster or line patterns, appropriate to its size. For each determination, time-resolved signals were carefully studied to select stable, non-fractionated intervals, ensuring that inclusions, zonation and core–rim features were always excluded from age calculations.

U–Pb results

Results of 84 spot analyses of zircons are shown in Table 1 and in the concordia diagrams and histograms of Figs 2 and 3. Although the analytical methodology and data reduction approach ensure that only isotopically homogeneous domains were considered for age calculations, analyses with discordancy higher than 30% were rejected. Furthermore, the $^{207}Pb/^{206}Pb$ ages of all discordant analyses are consistent with U–Pb concordant data points (Table 1), ensuring that age groups are not biased by the use of discordant analyses. U–Pb analytical results yielded the same zircon age populations in both samples and therefore data are presented together in Table 1 and Figs 2 and 3. This feature is consistent with the inferred equivalent stratigraphic position for both samples.

Samples OS-1 and OS-2 contain three main U–Pb age groups (Table 1, Figs 2 and 3). The younger group (*c.* 82% of the analyses) consists of zircons with ages ranging from *c.* 480 Ma to *c.* 610 Ma (Figs 2A and 3). The older groups consist of Palaeoproterozoic zircons in the age range *c.* 1950–2150 Ma (*c.* 15% of the analyses) and 2450–2500 Ma (Archean–Proterozoic limit) (*c.* 2–3% of the analyses) (Figs 2B and 3).

Within the first group, 37 analyses yielded Late Neoproterozoic ages (610–540 Ma), 24 analyses yielded Cambrian ages (540–500 Ma) and eight analyses yielded Early Ordovician ages (500–480 Ma).

Discussion

The data presented above provide a maximum depositional age for the Betanzos Unit at *c.* 480 Ma. There was no previous evidence for the age of the unit as neither palaeontological nor stratigraphic correlation criteria had constrained its stratigraphic age. This datum suggests that the deposition of the greywackes might have been coeval with the deposition of the Armorican Quartzite of the autochthonous terranes (Bonjour *et al.*, 1988; Fernández-Suárez *et al.*, 2002a).

Palaeogeographical links

The main feature of the zircon age populations in the greywackes from the Betanzos Unit is the lack of Mesoproterozoic zircons (Fig. 3), at variance with detrital zircon age populations in Neoproterozoic and Palaeozoic sedimentary rocks of the Iberian autochthonous terrane, which contain abundant zircons in the age range 900–1200 Ma (Fernández-Suárez *et al.*, 2000, 2002a).

A second feature of interest is that the zircon age pattern found in the greywackes matches that of Neoproterozoic and Early Palaeozoic metasediments from the Ossa Morena Zone in SW Iberia (Gutiérrez Alonso *et al.*, 2001), the north Armorican Domain (Miller *et al.*, 2001) and zircon cores in gneisses from the Moldanubian and Saxothuringian zones of the Bohemian Massif (Tichomirowa *et al.*, 2001, and references therein). This correspondence suggests a marked affinity of the Betanzos Unit with those domains of the European Variscides, which, in turn, are considered to have an affinity with the west African craton (Rocci *et al.*, 1991, and references therein). Further to this, the age span of the youngest age group in the greywackes (480–610 Ma) corresponds to the main episodes of pre-Variscan magmatic activity recorded in the Ossa Morena Zone (Ordóñez Casado, 1998) and the north Armorican Massif (Chantraine *et al.*, 2001, and references therein).

The presence of *c.* 2 Ga zircons reflects the existence of a Palaeoproterozoic basement in the Variscan belt of western Europe (Icartian basement, e.g. Samson and D'Lemos, 1998) and in the west African craton (Eburnean basement, e.g. Rocci *et al.*, 1991). The *c.* 2.5 Ga zircons attest to the presence of an Archean basement component in the Variscan belt of western Europe (e.g. Guerrot *et al.*, 1989).

The lack of Mesoproterozoic zircons suggests that the deposition of the greywackes took place in a realm with no access to detritus from either Laurentia or Baltica since recycling of cratonic areas of these continents would have yielded detrital material containing zircons in the age range *c.* 900–1600 Ma. The absence of Mesoproterozoic zircons is also an indication that recycling of pre-Neoproterozoic Amazonia or Neoproterozoic arcs developed on Amazonia were not involved at any stage in the evolution of the Betanzos Unit (cf. Fernández-Suárez *et al.*, 2000) because Mesoproterozoic events are widespread in this cratonic area (e.g. Keppie *et al.*, 2001, and references therein). The absence of Mesoproterozoic zircons further indicates that, at the time of deposition, the basin had no access to exposures of Precambrian–Cambrian autochthonous NW Iberia as recycling of these rocks would have also yielded zircons in the age range 900–1200 Ma (Fernández-Suárez *et al.*, 2000).

The age spectra (*c.* 480–610, 1900–2100, 2400–2500 Ma) found in the greywackes match those of major events in the west African section of northern Gondwana, where no high-grade Mesoproterozoic events have been identified. Therefore, and in conjunction with the above arguments, we suggest that the periphery of the west African craton of northern Gondwana is the probable provenance of the upper units of the Allochthonous Complexes of NW Iberia.

Thoughts on possible tectonic settings

Although further work is needed to refine the constraints on the pre-Variscan tectonic setting and evolution of the AC, a few constraints can be drawn.

Table 1 Laser Ablation ICP-MS U Pb analyses (concordant analyses in bold type)

Analysis no.	Isotopic ratios (2σ errors)			Age (Ma)			Preferred age* (Ma)
	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	$^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	
ap16b12	0.0901 ± 0.0009	0.7022 ± 0.0090	0.0565 ± 0.0006	556 ± 11	540 ± 11	472 ± 50	472 ± 25
ap16a09	0.0667 ± 0.0008	0.5217 ± 0.0073	0.0567 ± 0.0004	416 ± 10	426 ± 10	480 ± 34	480 ± 17
ap19a10	0.0780 ± 0.0004	0.6088 ± 0.0031	0.0567 ± 0.0003	484 ± 5	483 ± 4	478 ± 24	483 ± 2
ap16b10	0.0953 ± 0.0011	0.7469 ± 0.0076	0.0568 ± 0.0007	587 ± 13	566 ± 9	484 ± 34	484 ± 17
ap18a16	0.0791 ± 0.0007	0.6179 ± 0.0060	0.0566 ± 0.0005	491 ± 9	489 ± 8	476 ± 34	489 ± 4
ap20a12	0.0645 ± 0.0006	0.5072 ± 0.0092	0.0570 ± 0.0010	403 ± 7	417 ± 12	490 ± 76	493 ± 38
ap19b16	0.0582 ± 0.0008	0.4586 ± 0.0061	0.0571 ± 0.0002	365 ± 10	383 ± 8	496 ± 16	496 ± 16
ap16b16	0.0805 ± 0.0004	0.6295 ± 0.0045	0.0567 ± 0.0003	499 ± 5	496 ± 6	480 ± 24	498 ± 10
ap19a06	0.0801 ± 0.0008	0.6377 ± 0.0057	0.0578 ± 0.0005	496 ± 10	501 ± 7	520 ± 38	500 ± 5
ap19a15	0.0738 ± 0.0005	0.5824 ± 0.0045	0.0573 ± 0.0003	459 ± 6	466 ± 6	500 ± 26	500 ± 26
ap16b11	0.0925 ± 0.0009	0.7322 ± 0.0078	0.0574 ± 0.0006	570 ± 10	558 ± 9	506 ± 42	506 ± 21
ap19b13	0.0826 ± 0.0014	0.6527 ± 0.0075	0.0573 ± 0.0008	512 ± 16	510 ± 9	502 ± 62	510 ± 10
ap19a05	0.0565 ± 0.0003	0.4484 ± 0.0021	0.0576 ± 0.0002	354 ± 3	376 ± 3	512 ± 12	512 ± 12
ap17b13	0.0923 ± 0.0009	0.7348 ± 0.0082	0.0577 ± 0.0004	569 ± 11	559 ± 10	518 ± 28	518 ± 14
ap20a07	0.0837 ± 0.0009	0.6663 ± 0.0096	0.0577 ± 0.0006	518 ± 11	518 ± 12	518 ± 44	518 ± 6
ap20a06	0.0840 ± 0.0016	0.6695 ± 0.0107	0.0578 ± 0.0010	520 ± 19	520 ± 13	520 ± 74	520 ± 6
b06rim	0.0780 ± 0.0009	0.6221 ± 0.0086	0.0578 ± 0.0004	484 ± 10	491 ± 11	522 ± 28	522 ± 14
ap17a06	0.0846 ± 0.0004	0.6753 ± 0.0046	0.0578 ± 0.0004	524 ± 5	524 ± 6	522 ± 28	524 ± 3
ap19b12	0.0718 ± 0.0012	0.5736 ± 0.0106	0.0579 ± 0.0003	447 ± 15	460 ± 14	524 ± 20	524 ± 10
ap17b14	0.0843 ± 0.0012	0.6771 ± 0.0072	0.0582 ± 0.0003	522 ± 15	525 ± 9	538 ± 26	528 ± 4
ap20a13	0.0793 ± 0.0005	0.6347 ± 0.0055	0.0580 ± 0.0003	492 ± 6	499 ± 7	528 ± 24	528 ± 12
ap17a16	0.0851 ± 0.0011	0.6875 ± 0.0106	0.0585 ± 0.0008	527 ± 13	531 ± 13	548 ± 42	529 ± 6
ap17b15	0.0725 ± 0.0007	0.5800 ± 0.0072	0.0580 ± 0.0005	451 ± 8	464 ± 9	530 ± 40	530 ± 20
ap16a05	0.0859 ± 0.0006	0.6689 ± 0.0064	0.0565 ± 0.0005	531 ± 7	520 ± 8	468 ± 36	531 ± 7
ap18b15	0.0861 ± 0.0007	0.6855 ± 0.0064	0.0577 ± 0.0005	532 ± 8	530 ± 8	518 ± 38	531 ± 4
ap20a10	0.0854 ± 0.0008	0.6878 ± 0.0065	0.0584 ± 0.0005	528 ± 10	531 ± 8	542 ± 34	531 ± 5
ap18a10	0.0730 ± 0.0011	0.5852 ± 0.0126	0.0581 ± 0.0007	454 ± 13	468 ± 16	532 ± 54	532 ± 27
ap19a07	0.0864 ± 0.0007	0.6927 ± 0.0057	0.0581 ± 0.0005	535 ± 8	534 ± 7	534 ± 40	534 ± 3
ap19a09	0.0569 ± 0.0003	0.4559 ± 0.0029	0.0581 ± 0.0002	357 ± 4	381 ± 4	534 ± 16	534 ± 16
ap18b09	0.0803 ± 0.0011	0.6441 ± 0.0091	0.0582 ± 0.0006	498 ± 13	505 ± 11	536 ± 22	536 ± 22
ap19b10	0.0780 ± 0.0009	0.6259 ± 0.0074	0.0582 ± 0.0004	484 ± 11	494 ± 9	536 ± 32	536 ± 15
ap20a14	0.0779 ± 0.0014	0.6256 ± 0.0096	0.0582 ± 0.0006	484 ± 16	493 ± 12	536 ± 42	536 ± 21
ap17a09	0.0876 ± 0.0008	0.7035 ± 0.0061	0.0582 ± 0.0005	541 ± 10	541 ± 7	534 ± 34	541 ± 4
ap20a11	0.0507 ± 0.0006	0.4085 ± 0.0036	0.0584 ± 0.0004	319 ± 8	348 ± 5	544 ± 26	544 ± 12
ap17a11	0.0775 ± 0.0013	0.6254 ± 0.0078	0.0585 ± 0.0007	481 ± 16	493 ± 10	546 ± 48	546 ± 24
ap17a14	0.0886 ± 0.0010	0.7099 ± 0.0091	0.0580 ± 0.0009	547 ± 12	545 ± 11	530 ± 64	546 ± 5
ap19a12	0.0737 ± 0.0011	0.5936 ± 0.0100	0.0585 ± 0.0004	458 ± 13	473 ± 13	546 ± 32	546 ± 16
ap16b05	0.0864 ± 0.0006	0.6969 ± 0.0070	0.0585 ± 0.0004	534 ± 7	537 ± 8	548 ± 26	548 ± 13
ap17b06	0.0885 ± 0.0007	0.7174 ± 0.0072	0.0588 ± 0.0009	547 ± 8	549 ± 8	558 ± 66	548 ± 4
ap16a10	0.0698 ± 0.0006	0.5641 ± 0.0051	0.0586 ± 0.0002	435 ± 8	454 ± 7	550 ± 18	550 ± 9
ap16b09	0.0902 ± 0.0016	0.7190 ± 0.0099	0.0578 ± 0.0008	557 ± 18	550 ± 12	520 ± 62	550 ± 6
ap17b05	0.0897 ± 0.0007	0.7164 ± 0.0071	0.0579 ± 0.0005	554 ± 8	549 ± 8	526 ± 34	551 ± 5
ap17a12	0.0766 ± 0.0010	0.6204 ± 0.0097	0.0587 ± 0.0004	476 ± 12	490 ± 12	554 ± 28	554 ± 14
ap17b07	0.0904 ± 0.0009	0.7244 ± 0.0062	0.0581 ± 0.0005	558 ± 10	553 ± 7	534 ± 40	554 ± 4
ap19a13	0.0720 ± 0.0012	0.5819 ± 0.0095	0.0587 ± 0.0004	448 ± 14	466 ± 12	554 ± 26	554 ± 26
ap18a07	0.0754 ± 0.0006	0.6115 ± 0.0062	0.0588 ± 0.0005	469 ± 7	484 ± 8	556 ± 38	556 ± 19
ap19b08	0.0830 ± 0.0013	0.6724 ± 0.0078	0.0587 ± 0.0008	514 ± 15	522 ± 9	556 ± 56	556 ± 27
ap16a12	0.1000 ± 0.0007	0.8111 ± 0.0077	0.0588 ± 0.0004	614 ± 9	603 ± 9	558 ± 32	558 ± 16
ap16a07	0.0774 ± 0.0017	0.6284 ± 0.0134	0.0588 ± 0.0004	481 ± 21	495 ± 17	560 ± 28	560 ± 14
ap17b10	0.0902 ± 0.0010	0.7410 ± 0.0089	0.0596 ± 0.0011	557 ± 12	563 ± 10	586 ± 80	560 ± 5
ap18a06	0.0817 ± 0.0006	0.6632 ± 0.0062	0.0588 ± 0.0004	506 ± 8	517 ± 8	560 ± 28	560 ± 13
ap16b14	0.0913 ± 0.0010	0.7364 ± 0.0075	0.0585 ± 0.0007	563 ± 12	560 ± 9	546 ± 50	561 ± 5
ap20a15	0.0909 ± 0.0006	0.7414 ± 0.0045	0.0591 ± 0.0004	561 ± 7	563 ± 5	572 ± 30	563 ± 3
ap17a07	0.0819 ± 0.0009	0.6665 ± 0.0069	0.0590 ± 0.0004	507 ± 11	519 ± 8	564 ± 32	564 ± 16
ap19a16	0.0936 ± 0.0009	0.7441 ± 0.0063	0.0577 ± 0.0007	577 ± 10	565 ± 7	516 ± 52	565 ± 7
ap18a05	0.0779 ± 0.0007	0.6350 ± 0.0052	0.0591 ± 0.0003	484 ± 8	499 ± 6	568 ± 20	568 ± 10
ap19b11	0.0811 ± 0.0011	0.6605 ± 0.0092	0.0591 ± 0.0006	503 ± 13	515 ± 11	568 ± 46	568 ± 23
ap18a12	0.0780 ± 0.0009	0.6367 ± 0.0090	0.0591 ± 0.0006	484 ± 11	500 ± 11	570 ± 42	570 ± 20
ap20a09	0.0926 ± 0.0012	0.7583 ± 0.0143	0.0594 ± 0.0011	571 ± 15	573 ± 17	578 ± 82	572 ± 7

Table 1 (Continued)

Analysis no.	Isotopic ratios (2σ errors) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Age (Ma) $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Preferred age* (Ma)
ap18a09	0.0616 ± 0.0004	0.5037 ± 0.0040	0.0592 ± 0.0006	386 ± 5	414 ± 5	574 ± 42	574 ± 22
ap17b12	0.0931 ± 0.0011	0.7647 ± 0.0092	0.0596 ± 0.0008	574 ± 14	577 ± 11	586 ± 56	576 ± 5
ap18a11	0.0684 ± 0.0010	0.5611 ± 0.0085	0.0594 ± 0.0004	426 ± 12	452 ± 11	582 ± 26	582 ± 13
ap19b07	0.0882 ± 0.0007	0.7228 ± 0.0051	0.0594 ± 0.0004	545 ± 8	552 ± 6	582 ± 26	582 ± 26
ap17a13	0.0889 ± 0.0007	0.7317 ± 0.0064	0.0596 ± 0.0004	549 ± 8	558 ± 7	588 ± 28	588 ± 14
ap18b08	0.0856 ± 0.0009	0.7057 ± 0.0089	0.0598 ± 0.0006	529 ± 10	542 ± 11	596 ± 46	596 ± 23
ap17b11	0.0896 ± 0.0006	0.7425 ± 0.0079	0.0601 ± 0.0006	553 ± 7	564 ± 9	604 ± 42	604 ± 22
ap18b05	0.0819 ± 0.0009	0.6788 ± 0.0093	0.0601 ± 0.0009	508 ± 11	526 ± 11	606 ± 44	606 ± 31
ap17a15	0.0992 ± 0.0010	0.8193 ± 0.0071	0.0599 ± 0.0005	609 ± 12	608 ± 8	598 ± 34	608 ± 4
ap18b14	0.0792 ± 0.0014	0.6579 ± 0.0130	0.0602 ± 0.0005	492 ± 17	513 ± 16	610 ± 36	610 ± 18
ap19b09	0.4155 ± 0.0059	6.9321 ± 0.0624	0.1210 ± 0.0012	2240 ± 54	2103 ± 16	1970 ± 36	1971 ± 17
ap16a13	0.4587 ± 0.0041	7.8892 ± 0.0663	0.1246 ± 0.0009	2434 ± 36	2218 ± 15	2022 ± 26	2022 ± 26
ap16b13	0.3550 ± 0.0034	6.1272 ± 0.0466	0.1252 ± 0.0007	1958 ± 32	1994 ± 13	2030 ± 20	2030 ± 10
ap16a06	0.3723 ± 0.0030	6.4972 ± 0.0669	0.1265 ± 0.0009	2040 ± 28	2046 ± 18	2048 ± 26	2046 ± 10
ap17a05	0.2875 ± 0.0035	5.0095 ± 0.0616	0.1262 ± 0.0010	1629 ± 35	1821 ± 21	2046 ± 26	2046 ± 13
ap19b05	0.3271 ± 0.0035	5.7224 ± 0.0778	0.1269 ± 0.0007	1824 ± 34	1935 ± 24	2054 ± 20	2054 ± 20
ap19a11	0.3419 ± 0.0022	5.9870 ± 0.0383	0.1270 ± 0.0007	1896 ± 21	1974 ± 11	2056 ± 20	2056 ± 20
ap17a08	0.3089 ± 0.0037	5.4265 ± 0.1292	0.1272 ± 0.0016	1735 ± 36	1889 ± 41	2060 ± 44	2060 ± 22
ap16b07	0.4079 ± 0.0023	7.2009 ± 0.0475	0.1280 ± 0.0006	2205 ± 21	2137 ± 12	2070 ± 16	2070 ± 16
ap19b14	0.3625 ± 0.0025	6.4196 ± 0.0449	0.1284 ± 0.0004	1994 ± 23	2035 ± 12	2076 ± 12	2076 ± 12
ap19a08	0.3514 ± 0.0025	6.3464 ± 0.0324	0.1310 ± 0.0007	1941 ± 24	2025 ± 9	2110 ± 18	2110 ± 18
ap18b12	0.3142 ± 0.0048	5.7188 ± 0.0806	0.1320 ± 0.0003	1761 ± 47	1934 ± 24	2124 ± 8	2124 ± 8
ap20a08	0.3573 ± 0.0043	6.6232 ± 0.0854	0.1343 ± 0.0009	1970 ± 40	2062 ± 23	2154 ± 24	2154 ± 24
ap18a13	0.3820 ± 0.0029	8.4559 ± 0.0939	0.1603 ± 0.0010	2086 ± 27	2281 ± 20	2458 ± 20	2458 ± 20
ap16a08	0.4751 ± 0.0057	10.5643 ± 0.0750	0.1612 ± 0.0016	2506 ± 49	2486 ± 13	2466 ± 34	2484 ± 7
ap16b06	0.3917 ± 0.0045	8.7933 ± 0.1293	0.1628 ± 0.0010	2131 ± 41	2317 ± 27	2484 ± 20	2484 ± 20

*Age and error for concordant analyses are calculated according to Ludwig (1998). For discordant analyses the $^{207}Pb/^{206}Pb$ ages were used. Errors for discordant 'preferred ages' are those of upper intercept forced through 0 ± 5 Ma.

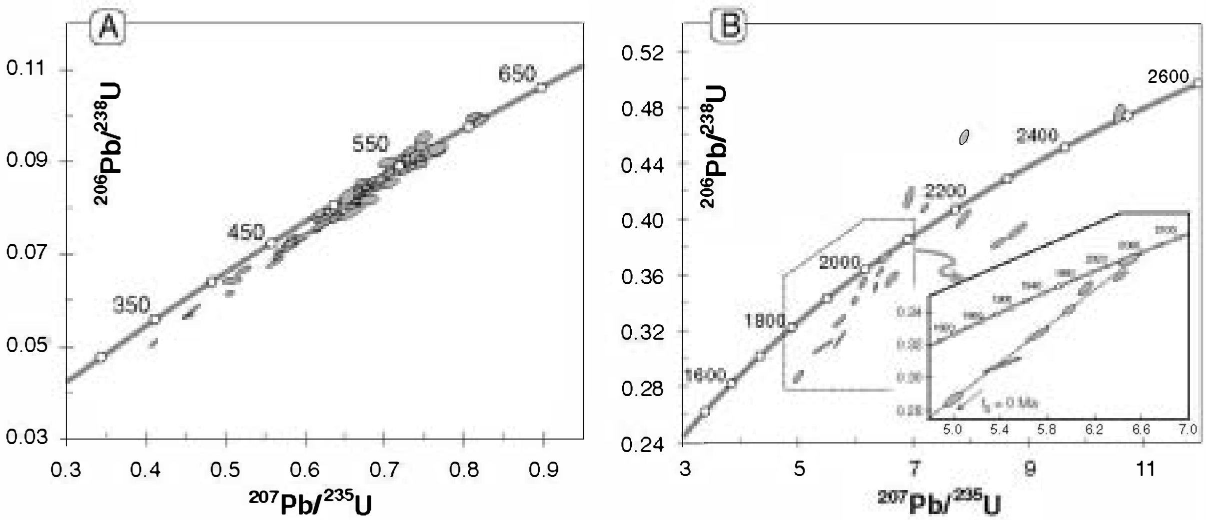

Fig. 2 U Pb concordia diagrams showing the results of LA ICP-MS dating of zircon (error ellipses represent 2σ uncertainties). (A) Phanerozoic and Neoproterozoic zircons. (B) Palaeoproterozoic and Archaean zircons. Inset is shown to illustrate that a significant number of analyses have consistent $^{207}Pb/^{206}Pb$ ages around 2 Ga.

It is widely accepted that the Ordovician Armorican Quartzite was deposited in a platform bordering the African margin of Gondwana (e.g. Paris and Robardet, 1990) and it contains abundant Grenvillian zircons (Fernández-Suárez *et al.*, 2002a). It has also been proposed that the source for those Grenvillian zircons is crustal fragments originated in the Amazonian margin of Gondwana and accreted to the African margin in the Early Palaeozoic by major strike slip faults (Fernández-Suárez *et al.*, 2002a). In view of the arguments presented in the

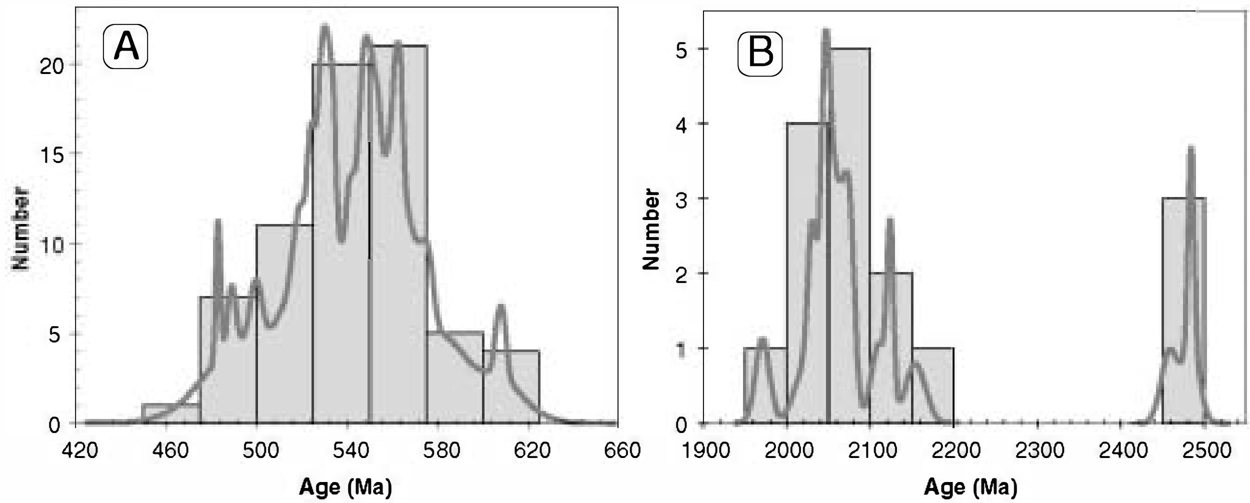

Fig. 3 Age histogram and cumulative probability plot. The plot has been constructed using the concordia ages and errors (Ludwig, 1998) for concordant analyses and the $^{207}Pb/^{206}Pb$ ages for discordant analyses. Errors for discordant analyses are derived from the upper intercept error of a discordia line forced through 0 Ma. A and B as in Fig. 2.

above section, we interpret this as an indication that the crustal element whose erosion produced the greywackes of the Betanzos Unit had been detached from the margin prior to the lateral accretion of Amazonia-derived blocks to the African margin. Therefore, at the time of deposition of the Armorican Quartzite on the Gondwanan platform there existed either a wide enough ocean separating the margin from the depositional locus of the greywackes or a barrier that impeded the access of detrital material from the continent. The latter possibility is compatible with a setting in which oceanic subduction and arc construction took place beneath the detached element. In such a case, the arc would have acted as a barrier for sediments shed by the continent and in this situation the basin separating the continent from the detached element need not be very wide. This scenario implies that the greywackes would have been deposited as fore-arc sediments, which is consistent with their sedimentological features (Díaz García, 2000).

In addition to the above, the U–Pb age spectra of detrital zircons in the greywackes of the Betanzos Unit are consistent with SHRIMP ages of zircon cores in high-grade metasediments of the underlying HP-HT units (Ordoñez Casado, 1998), suggesting that these units may represent variously metamorphosed and deformed sediments with the same source area and likely deposited in the same basin. If this had been the case, and considering that the metasediments in the HP-HT units underwent high-grade and HP metamorphism at *c.* 500–490 Ma (Fernández-Suárez *et al.*, 2002b), then an environment where crustal subduction took place ought to be invoked to account for that contingency. In such a context, the greywackes could be considered to represent an overstepped sequence of an arc edifice under which the HP and IP units were buried and exhumed in a short time span (< 10 Ma, Fernández-Suárez *et al.*, 2002b). In this setting, the youngest zircon population of the greywackes might record dismantling of the *c.* 500 Ma (Abati *et al.*, 1999) arc rocks. However, available geological and geochronologic data do not allow further constraints to be placed on the features of this suggested setting.

Synthesis

The data and observations discussed above are consistent with the following hypothesis.

The upper units of the Allochthonous Complexes of NW Iberia represent a fragment of the African section of Neoproterozoic Gondwana that was detached from the margin in pre-Ordovician times as a result of extension following the main episode of Cadomian–Avalonian arc construction and terrane accretion (cf. Murphy *et al.*, 2000). This detachment might have taken place in the context of the opening of the Rheic oceanic realm. The basin thus created separated the margin of Gondwana from a detached element made up of cratonic basement *c.* 2 Ga old (plus some Archean component) and Cadomian–Avalonian arc material, which constitute the main source for the greywackes of the upper units of the AC. In the Early Ordovician, this basin was wide enough for sediments from the margin to be unable to reach the greywacke basin. Alternatively, the greywackes could have been deposited as fore-arc sediments in a scenario of continentwards subduction and arc construction on the extended Gondwanan margin. In either case our contention is that the upper units of the AC may represent detached counterparts of Ossa Morena and the north Armorican Domain resulting from the Early Palaeozoic break-up of the Gondwanan margin that were eventually thrusted back upon it during the course of the Variscan collision.

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